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METEORS*

By R. A. McIntosh

METEORS consist mainly of masses of iron and stone. Although other elements are present in small quantities, analyses reveal that iron or stone, or the two in fairly equal proportions, are the main constituents. These meteoric bodies range in size from specks of dust to masses weighing many tons. The solar system in the neighbourhood of the earth is fairly uniformly filled with meteoric masses of various sizes, the majority being grouped together in families pursuing common orbits through space.

As the earth moves through space, encounters with these minute bodies are frequent, so that a second cannot pass without at least one meteor entering some portion of the earth's atmosphere. As a meteor enters the atmosphere its velocity is to some extent retarded by the resistance of the air, and the kinetic energy of its motion is transformed into kinetic energy of the gas molecules which it hits and of the molecules of its surface. In other words, both the air and the surface of the meteor are greatly heated by the friction created by its motion and the resistance of the atmosphere. The surface layers of the meteor liquefy and vaporize and an envelope of incandescent gas and vapour many times larger than the meteor itself spreads around and is swept behind it. This process continues until the whole body is vaporized or until the resistance of the

*Adapted from a lecture delivered before the Auckland (N.Z.) Astronomical Society, 1930, December 11.

atmosphere causes the velocity of the meteor to fall below a certain value. It is the envelope, and not the body itself, which emits most of the visible light.

The appearance of a meteor is therefore largely governed by its velocity. The average meteor at the earth's distance from the sun moves with a velocity of 26 miles a second. The earth itself is moving with a velocity of 18 miles a second. Thus if the earth encounters a meteor moving in the opposite direction the relative velocity of the meteor will be the sum of its real velocity and the earth's velocity, or 44 miles a second. At such a speed the meteor stands little chance of penetrating far into the earth's atmosphere. Unless exceptionally large, it quickly burns away, appearing to us below as an ordinary meteor. If a meteor overtakes the earth, however, its relative velocity is the difference between its real velocity and that of the earth, namely 8 miles a second. Such a body would take a long time to entirely vaporize, its apparent flight would be long and slow, and it would have a good chance of reaching the earth's surface as a solid body.

The Study of Meteors

This brings us to some necessary sub-divisions of meteors employed in meteoric astronomy. The term meteoroid is applied to all meteoric matter in the solar system which has not become visible by encounter with our atmosphere. Once the meteor has become visible, however, it falls within one of two main classes. A meteor whose apparent magnitude is comparable with that of the fixed stars retains the term "meteor," a term also used to denote the whole range of meteoric phenomena. A body of exceptional brilliance, however, is termed a fireball. If a mass, either meteor or fireball, succeeds in penetrating fully the earth's atmosphere and reaches the ground, either in one mass or as shattered fragments, it becomes a meteorite.

The ordinary meteor, as already pointed out, is similar in brightness to the fixed stars. An analysis of several thousand observed by the writer in recent years reveals that their average brightness is the third magnitude. From the brightest to the faintest seen there is a marked increase in numbers until we reach the fourth

magnitude, when the number begins to fall off. There are several reasons which make us convinced that this falling off in numbers for the fainter meteors is apparent rather than real. Probably great numbers of fifth and sixth magnitude meteors are missed because of their faintness. About 30 per cent. of all meteors seen are coloured, one-third of the number being of reddish hue. In the remaining 70 per cent. no colour can be detected. The average meteor may have a duration of from a tenth of a second to a second. Fireballs, however, may endure for as long as ten seconds. The average for all meteors is almost exactly half a second. The apparent paths of meteors vary considerably in length. Some do not move at all, others cover arcs up to 90° in length. About four meteors in every hundred (from the writer's observations) are abnormal. This abnormality may arise in a number of ways. Changes of brightness may occur during flight; instead of arcs of great circles, the meteors may cover irregular or spiral paths or appear to fly across the sky in a series of jerks, or remarkable nuclei or trains may be in evidence.

Meteors come from all parts of the sky, as well as from small areas. A single observer may expect to see an average of ten meteors an hour on an ordinary night. The total number which enters our atmosphere in a day bright enough to be visible to the naked eye must be several millions, and in addition there is probably a still larger number so faint as to be observable only with a telescope.

When we come to a consideration of the number of meteors visible at any hour of the night we must remember that this number depends on the position of the observer. When it is 6 p.m. local time an observer looking toward his meridian is also looking toward that point in space from which the earth is receding. Hence the majority of the meteors which are seen at that time are those which overtake the earth. At 6 a.m. an observer looking toward the meridian is also looking toward that point in space toward which the earth's motion is then directed. The earth is moving toward the meteors and the number of encounters is therefore much greater than in the early evening. The point toward which the earth's

motion is directed is termed the meteoric apex, or the apex of the earth's way, and is found on the ecliptic between 89° and 91° preceding the sun.

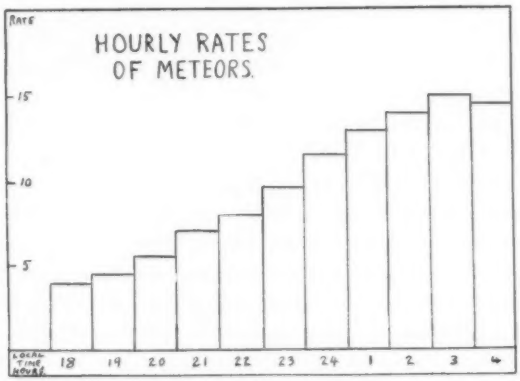

FIG. 1. Diagram illustrating the variation in the number of meteors visible during each hour of the night.

The diagram (Fig. 1) illustrates the number of meteors visible in each hour of the night. It will be seen that the numbers increase to a maximum at 3 a.m. From then on there is a falling off, due possibly to the presence of twilight on most nights. To secure large numbers of meteors the observer must therefore concentrate his energies on the morning hours. Latitude also has a bearing on the number of meteors seen.

When we come to consider the monthly rates of meteors we find that the position of the meteoric apex remains the deciding factor. As meteors are most numerous around the apex it follows that most meteors will be seen when the apex is at its greatest elevation at midnight. The apex reaches its greatest height above the horizon three months later than the sun, or in the autumn. In the spring it is at its lowest, and fewer meteors can be expected on these nights. Although this statement would be evident in data collected by observers if the meteors were fairly uniformly scattered in space, it is well known that the earth encounters some particularly rich

meteor streams, such as the Aquarids and Perseids, and the large numbers of meteors observed during the activity of such meteor showers upset the smoothness of the curve of frequency.

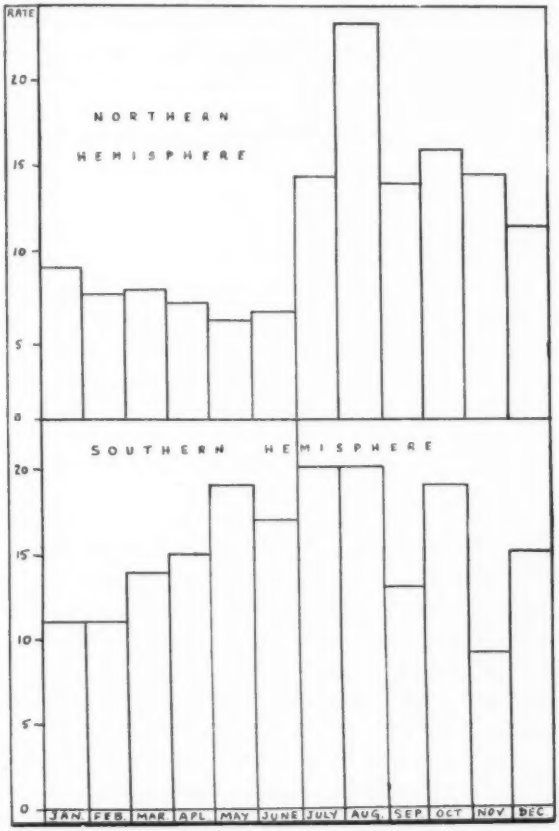

FIG. 2. The monthly rates of meteors in northern and southern hemispheres compared.

The term meteor shower often appears in text books, and is often used by the meteor worker of the present day, and perhaps

some speculation has arisen on the exact definition of a shower. In the past some awe-inspiring meteor displays have occurred which have fully justified the term "shower," the meteors appearing so thickly that for hours on end the sky has been full of raindrops of fire. Many notable showers occurred during last century, in some cases as many as ten thousand meteors being estimated as visible to one observer in an hour. It is no wonder that the ignorant were terrified, while astronomers themselves were so awed by the magnificence of the spectacles that few precise observations were made. However, these showers served their purpose both in awakening general interest in astronomy and in turning the activities of some astronomers to the elucidation of the many problems presented.

A modern meteor shower is but a pale imitation of the splendid displays of the past. There are occasions when a trained meteor observer may see as many as 30 or 40 meteors in an hour, or perhaps more than 60 an hour if he is merely counting and not recording. Such displays still retain the title of meteor showers. To an observer accustomed to seeing an average of ten meteors an hour over more than half the year these showers are rich indeed, although the general public would hardly find the numbers striking.

When the great showers were witnessed last century observers noticed the tendency of the meteors to appear to emanate from the same point in the sky. No matter what the height of this point above the horizon, this apparent radiation persisted, and meteors all over the sky could be traced back until their paths appeared to intersect. The spot from which the meteors appeared to come was termed the radiant point of the shower, and the shower was named after the constellation or star near which the radiant lay. Thus we have the Orionids, a shower which radiates from the northern portion of Orion in the middle of October, and the Eta Aquarids, a southern meteor shower visible near the star Eta Aquarii early in May.

Phenomenon of Radiation

The determination of meteor radiants is one of the principal tasks of the meteor observer. Provided with maps of the whole sky and sheets for recording various statistics, a meteor observer

spends his time scanning the sky, noting as exactly as possible the path of each meteor seen, at the same time recording its magnitude, duration, and other particulars of its appearance. Later the maps are examined at leisure. The paths of the meteors are traced backwards and any intersections are examined. It is here that the skill of the meteor observer is mainly employed. With practice, anyone can plot reliable paths on the maps, but it is a vastly different matter to sort out from the maze of intersecting paths those groups which constitute real radiants and those which are merely chance intersections.

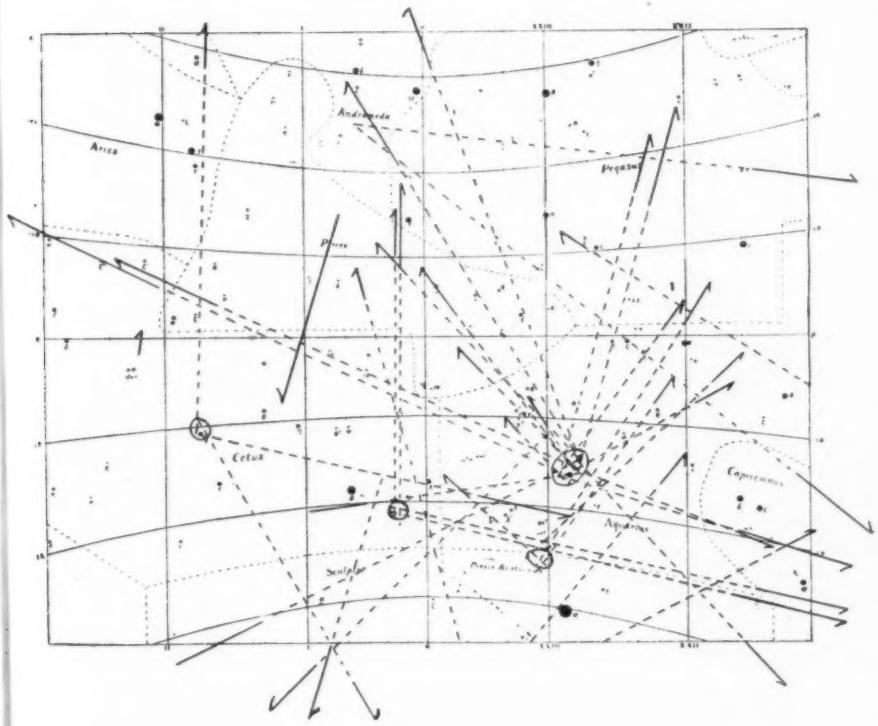

FIG. 3. A meteor map showing radiants.

A map from the writer's records is illustrated in Figure 3. The paths are traced to their intersections and the radiants become obvious. The map is useful in showing the general phenomenon of radiation. In the first place it will be seen that meteors can be seen in any position relative to the radiant—they occur at all position angles and all distances. When a radiant is low in the sky few meteors will be seen below the radiant, the majority being scattered above. When the radiant is high the meteors will appear equally frequently in all directions. When the radiant is low in the sky the meteors begin at a considerable distance from the radiant point, travel slowly over long paths, and frequently leave luminous trains in their wake. When a radiant is nearly overhead the meteors are seen in all parts of the sky, but most frequently close to the radiant. They travel swiftly over short arcs, endure for less than the average time, are generally not very bright, and do not often leave trains.

The phenomenon of radiation is really an effect of perspective. Meteor swarms in space consist of millions of meteoroids travelling in parallel paths. A widely known law of drawing is that parallel lines must be drawn converging to a vanishing point. The meteors, moving in parallel lines, also converge to a vanishing point, which is the apparent radiant point. Therefore the determination of radiants gives us information of the directions of the various meteor streams in space, and it is a comparatively simple matter, once the velocity of the meteors is known or can be assumed, to calculate the exact paths they pursue in space.

Since the radiant point is the apparent direction of a meteor stream as seen from the earth, it necessarily follows that every radiant must shift from day to day, since the direction of the earth's motion is continually changing, while that of the meteor stream remains unchanged. The observed radiant point should maintain always the same distance from the sun, so that to an observer it should appear to shift about a degree a day eastwards through the constellations. In the case of a wide stream of meteoroids the radiant can be observed to shift a considerable extent. In most cases, however, the earth traverses the full width of a meteor stream in a few days and the shifting of the radiant is masked by the inevitable errors of observation.

The position of a radiant is influenced by other causes beside the orbital motion of the earth. The attraction of the earth on the meteors and the rotation of the earth both have their effect. In extreme cases the shift in a radiant due to the earth's attraction can amount to 17°, but in most cases is less than a degree and can safely be neglected. The rotation of the earth introduces a very small shift in the radiant, which is almost always ignored by meteor workers.

For many years the belief was held that meteor streams sometimes furnished radiants which did not display the daily motion required by theory. With the application of better methods of observation and more rigid definition of what a radiant is, these stationary radiants have, one by one, been proved to be in motion, the direction and the amount of the shift being that required by theory.

Cometary Origin of Meteor Streams

Once a mathematical method of calculating the orbits of meteor streams had been evolved a number of the most prominent radiants were used to determine the orbits pursued by their constituent meteors, and it was soon discovered that most of these meteor showers were following paths through space very similar to well-known comets. The obvious conclusion was that the meteors and comets were in some way related—either the comets were built up from the meteoric particles or the meteors were the residue left behind by the comets.

Without delving into the nature of comets to any extent, we may state that the view held by astronomers is that the meteoric particles encountered by the earth are the debris of comets—not their origin.

The tail particles of comets, forced from the nuclei probably by the sun's radiative pressure, are too small to be responsible for the meteors we see. These appear to arise from debris in the nuclei, which consist of millions of small particles packed comparatively closely together.

A comet loses part of its material on each visit to the sun. The material thus lost is scattered behind the comet and travels therefore in the same orbit as the parent comet. In the case of a period-

ical comet which has returned many times to the sun's neighbourhood, the ejected material must be scattered fairly evenly all around the orbit. In the case of a comparatively new comet, the material must follow closely upon the comet itself. In the former case we can expect to see a meteor shower recurring annually in a certain portion of the earth's orbit; in the latter case the meteor shower would be visible for only one or two years after the perihelion passage of the comet.

An essential to the visibility of a meteor shower from a comet is that the orbit of the comet (and its accompanying meteor stream) must pass through or very close to the earth's orbit. Although a large number of comets are observed to have perihelion distances which bring them well within the earth's orbit, it generally happens that at the points where the comet orbit passes the earth's the comet is high above or below our path and no encounter can therefore take place. The comet must be at or near its line of nodes when passing the earth's orbit to render a meteoric shower possible.

Though there are several hundred comets known, there are comparatively few of them which satisfy the essential requirement of intersecting the earth's orbit at or near a node, and therefore there are only half a dozen cases in which the association of meteor streams with known comets has been proved, and perhaps as many more cases in which association is strongly suspected. We cannot work in the opposite direction and say that every meteor shower seen should have a parent comet. Comets are comparatively short-lived bodies, while the meteoric matter they scatter behind them may exist for many thousands of years after the comet has disappeared. The observer of a meteor shower may be witnessing a display from the debris of a comet which had its being centuries before there was intelligent life on this globe.

The perturbations of the various planets on a meteor stream after the death of a known comet, the gradual thinning of a meteor stream with its successive encounters with the earth, and the dispersive action of the earth on those members of the stream which escape complete annihilation are other factors tending to hide from us the parentage of a meteor stream.

Two examples can be cited in illustration of these points. When first discovered Biela's comet was a normal object in every way, and so it remained through several returns to our neighbourhood. Then, upon one return, it was found to have broken into two comets, which travelled together through the sky. Subsequently the comet was lost and has not since been recovered, its complete disruption probably having occurred. The meteoric matter connected with this comet has long been known to us, providing what was once a brilliant display from Andromeda at the end of each November. But in recent years the number of meteors visible has been growing steadily less, and nowadays the shower is hardly worth watching for. The gradual thinning of this meteor stream has almost certainly been occasioned by the dispersive action of the earth.

Tempel's comet has provided us with some wonderful meteoric showers in the past at intervals of a third of a century. Such displays occurred in 1833 and 1866, and another was confidently expected in 1899. A close approach of the meteoric stream to Jupiter, however, perturbed the stream to such an extent that only a few stragglers from this rich shower are encountered annually. The shower of 1899, as foreseen too late, was a complete fiasco, and astronomy generally suffered a great setback in popular opinion ..cordingly.

Meteor streams are not only lost to us by the perturbations of other planets—they can be given to us by the same agency. The well-known comet Pons-Winnecke has in the past suffered great changes in its orbit through planetary attraction and in 1916 the orbit had been so changed that the earth passed through the meteoric stream accompanying the comet and a splendid display of meteors was widely witnessed. Upon its next return the orbit had suffered further changes and no meteors were seen.

Fireballs

Fireballs are similar in nature to ordinary meteors. It seems that the three main types of shooting star can be accounted for by differences in their masses and velocities. The meteor, being very small and possessing a high velocity, is rapidly consumed in its passage through the atmosphere, and therefore does not last as long

or become as brilliant as the fireball, which, although larger, still does not possess sufficient mass to reach the earth whole. Meteorites, similar in appearance to fireballs, generally appear on the hindmost side of the earth and therefore have low apparent velocities, which enable them to reach the earth before they are completely vaporized.

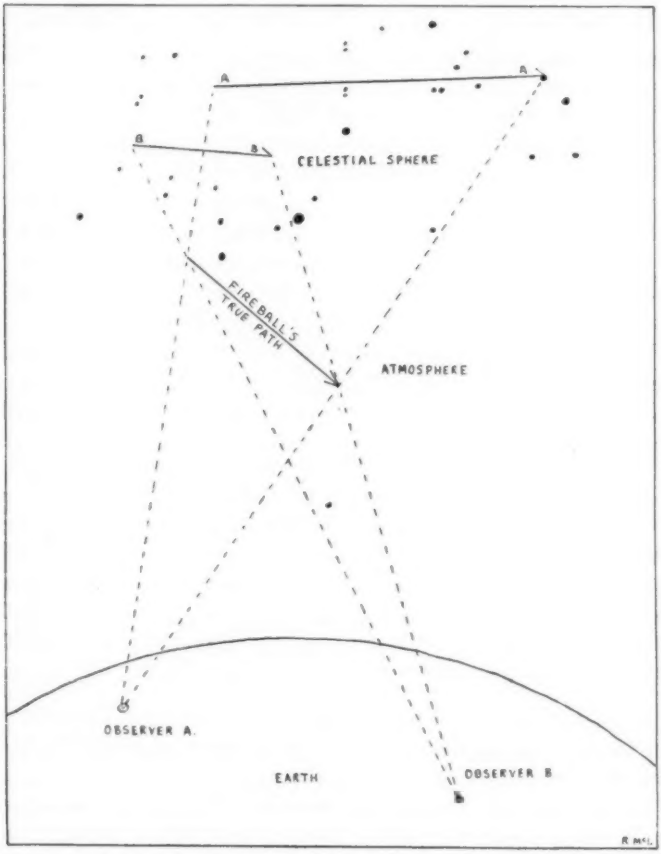

FIG. 4. How duplicate observations of a fireball enable its real path to be determined.

Meteors appear generally between 70 miles and 50 miles above the earth's surface. Fireballs appear generally about 80 miles above the earth and disappear about 30 miles high. Their paths are sometimes as much as 200 miles long, compared with an average length of 35 miles for meteors.

On account of their great brightness, fireballs are good subjects for photographic study, and many pleasing photographs of them appear from time to time in astronomical journals. With the fastest lenses and plates obtainable, meteors of the second magnitude, or as bright as the stars in Orion's belt, are the faintest objects which yield photographic images. The fireballs, on account of their great brightness, give good photographic images in which much detail can be discerned, compared with the faint streaks left on plates by ordinary meteors.

As all meteoric phenomena occur quite close to us, speaking astronomically, it is possible to obtain exact data as to their paths in the atmosphere by employing the same methods as a professional astronomer does in the determination of stellar distances. A base line several miles in extent is sufficient to give us a measurable shift through parallax if photography is employed. A longer base line is necessary, however, if reliable data are to be secured from visual observations (Fig. 4). In England and America this method of studying meteors has become deservedly popular in recent years, and news has recently been published that the Harvard Observatory is about to operate a chain of stations for studying the real paths of meteors and fireballs.

In New Zealand, unfortunately, the observers are too scattered to enable such a plan to be carried out, but there remains another line of attack which has been the mainstay of meteoric workers in other lands. When a bright fireball is witnessed an appeal to the press generally results in bringing to light a number of people who have seen this object. By collecting the scanty and somewhat hazy information that these persons are able to supply from their widely scattered stations it is sometimes possible to arrive at a very good estimate of a fireball's real path. The confused data and the apparently contradictory reports, however, generally lead the com-

puter to believe that a whole flock of fireballs has appeared, and it is only with experience and some luck in selecting the most accurate observations that the computer is able to produce anything of value, at least in this country, where the population is scattered and generally blissfully ignorant even of the compass points.

When fireballs penetrate below 30 miles above the earth's surface their flight is generally accompanied by detonations caused by the ballistic wave set up in the atmosphere of the body's rapid flight. The study of these detonations is a comparatively new branch of meteoric astronomy, but one of great importance to the meteorologist, as it gives a clue to the state of the upper atmosphere.

Immediately about the region where the fireball falls there is a zone in which detonations are heard. Generally like thunder or gun fire, these noises appear to vary with different fireballs. Sometimes they are of sufficient intensity to shake houses and cause windows to rattle. Beyond the zone where the detonations are heard there is an area where no sound is heard, and, further away, another region in which the detonations are plainly heard. It is believed that the sound heard in this latter region comes from sound waves which originally went upwards in the atmosphere and were reflected back to fall a considerable distance from the place where the fireball fell.

As the velocity of sound varies according to the temperature of the air, we have here an excellent means of determining the temperature of the atmosphere, provided always that we can get accurate estimates of the interval between the visibility of the fireball and the occurrence of the detonations. Unfortunately such accurate observations have not yet been secured.

Meteor Trains

The apparition of some meteors and most fireballs is accompanied by a wonderful luminous train, persisting sometimes for many minutes. The glow of the train, if bright, is usually yellowish or greenish in colour, but generally when faint it appears white.

Our knowledge of meteor trains is still very limited. Simultaneous observations of remarkable trains have proved that they are several miles in length and occasionally one or more miles in

diameter. They therefore fill several cubic miles of space with their faint glow. We know that the bodies which produced these trains are very small and could not have filled one millionth of the space illuminated. It is therefore a mystery how such trains could be produced and how they can remain luminous for so long in the supposedly cold and tenuous regions of the upper atmosphere.

Meteor trains have an average altitude of 54 miles, with upper and lower limits of 60 and 50 miles respectively. The height at which a meteor begins or ends does not seem to have any effect on the height of the train. Some meteors seen in daylight leave behind them trains which are not luminous but appear like a trail of smoke across the sky. The late Professor Trowbridge, who devoted a considerable time to the study of meteor trains, has stated:—"When a body is very hot an immense number of negatively charged corpuscles or ions are given forth. Air containing free ions becomes a conductor of electricity, hence we have in a meteor rushing through the atmosphere a condition extremely like a very long electrical discharge tube containing gas at low pressure. The burning meteor must form a column of highly ionized air. Moreover, at a certain altitude, corresponding to a barometric pressure of 0.2 mm. the conditions are precisely right for the formation of phosphorescence in the meteor track. When the meteor nucleus has been consumed all that remains visible in the dark sky is the body of phosphorescent gas in the part of the track where the gas pressure conditions were correct for the formation of the persistent glow."

Meteorites

Less than two centuries ago the existence of meteorites was denied by scientists, in spite of numerous records extending back through 2,500 years attesting that stones had been seen to fall from the heavens. Ancient Chinese records often mentioned falling stars and the number of stones recovered. In other countries meteoric stones have been preserved as objects of worship, notably the "Image of Diana" at Ephesus and the sacred stone of the Moslems at Mecca.

A shower of more than a thousand meteoric stones which fell

in France in 1803 finally forced the scientists to the conclusion that the missiles were really of celestial origin. Nowadays the meteoric origin of these stones is undoubted, and many examples are stored in our museums. Although sometimes a single stone, usually a meteoric fall consists of many pieces, sometimes to be counted in thousands. A meteorite which fell in Russia in 1869 was estimated to consist of more than 100,000 pieces, most of them very small.

The most characteristic feature of meteorites is a thin black crust, usually, but not always, glassy in appearance. This crust results from the fusion of the meteorite's surface during its swift rush through the air, and in some cases penetrates deep into the mass through grains and fissures.

The crusted surface usually exhibits pits and hollows termed "thumb marks" because they so resemble prints produced by thrusting the thumb into soft clay. These cavities are formed by the burning out of the more fusible substances contained in the meteorite.

The large majority of meteorites are composed of stone, being masses of crystalline rock. Some, however, are alloys of metallic iron, nickel and cobalt. Others are mixtures of stone and iron. A very small proportion of the meteorites seen to fall and recovered are found to be composed of iron. About half the number exhibited in the museums, however, are iron meteorites. The principal reason for this is, not the greater number of iron falls, but the fact that an iron meteorite when found is recognized instantly as something unusual, while stony meteorites, except to the trained observer, look like any other stones.

On examining the structure of the various types of meteorite it is found that in stony meteorites this structure is of rounded crystalline grains, while in the iron objects the crystalline structure is distinctive and quite unlike that of stony meteorites. These structures indicate that the material must have cooled from a molten condition—rapidly for most stony meteorites and more slowly in the case of the iron ones.

Meteorites are classified under three named groups, (1) Aerolites, consisting of silicate minerals with small amounts of metallic

alloys and sulphides (*i.e.* stony), (2) Siderolites, made up of a network of metals with the spaces between filled with silicate materials (iron and stone), and (3) Siderites, which contain mostly iron and nickel, or their alloys, along with iron phosphides and sulphides (iron).

The following elements are found abundantly in meteorites:— Aluminium, calcium, carbon, iron, magnesium, nickel, oxygen, phosphorus, silicon and sulphur. Sixteen other elements, including hydrogen and nitrogen, have been found, and probably argon and helium besides. The fact that no new element has been found in these messengers from outer space gives strong confirmation to the belief in the essential chemical unity of the universe.

The largest meteoric stone seen to fall and recovered intact was the Paragould (U.S.) stone which fell on February 17, 1930. It weighed 820 pounds. Although bodies recovered after their fall has been witnessed are generally not very large, a number of objects have been found and proved by structure and appearance to be of meteoric origin. Among this class there are some very large objects indeed.

For many years the record in this class had been held by a mass brought from Greenland by Peary which weighed 36½ tons. The Grootfontein meteorite in South Africa has, however, recently claimed the record. As it has been impossible to move it from the spot where it fell, only a rough estimate of its weight has been made, and in all probability it is not less than 50 tons.

Perhaps the largest meteoric mass has not yet been recovered. In the smooth desert plain of Canon Diabolo, Arizona, there is a huge pit dug out of the surface many hundreds of years ago, which in all probability was formed by the impact of a huge meteorite. Within a six-mile radius of the crater more meteoric iron has been picked up than has been found in any like area of the globe.

The crater itself is 4,200 feet in diameter, and a walk around the rim is a three-mile journey. The bottom of the crater is 440 feet below the surrounding desert and 570 feet below the rim. Extensive borings in the floor of the crater have failed to reveal the existence of a mass of iron, although when drilling was aband-

oned in 1922 the drill had encountered something hard and solid at a depth of 1,376 feet and the toll could not be recovered. Probably the goal of 18 years' effort had been attained, but the remarkable crater had not divulged its secret.

Another remarkable instance of the destructive nature of a large meteorite was provided by the great Siberian meteorite which fell on June 30, 1908. The meteorite fell in that part of Siberia which lies to the north of China, yet the blast of air generated by its rush toward us devastated forests over a range of hundreds of miles. Remarkable air waves were recorded on sensitive barographs in England, the waves having taken five hours to travel from the point where the meteorite fell. Several observatories recorded seismic waves, the most distant being Jena in Switzerland. No crater comparable to that in Arizona has been found, but a Russian expedition has recently discovered several square miles of ground pitted with holes ranging from 10 to 50 yards in diameter which are probably the graves of fragments of the meteorite.

Although an average of four meteorites a year have been seen to fall and have been recovered since 1850, and naturally many more must have escaped detection, there is no authentic record of a meteorite having proved fatal to human life. In spite of the millions of meteors which enter the earth's atmosphere in the course of a day we can breathe freely, confident that of the small percentage which eventually find their way to the earth's surface a remarkably small number will be responsible for death or injury.

THE 1932 TOTAL SOLAR ECLIPSE*

By A. VIBERT DOUGLAS

A TOTAL eclipse of the sun is a phenomenon of such striking and unforgettable character that no persons who can possibly be within the favoured area at the right time should allow trivial circumstances or apathy to prevent them from making the attempt to see it. The majority of mankind live their lives through and die without ever seeing this solemn and impressive spectacle.

To have the path of totality come to one's very door is an event only likely to happen once in 360 years. Hence those whose span of life brings them onto the doorstep at the right time are extremely fortunate.

The total eclipse of the sun which will take place in the afternoon of August 31st, 1932, will offer just such an opportunity to many thousands of people living within or visiting a strip of the earth's surface about one hundred miles wide running diagonally across part of the Arctic Ocean, the northerly islands of Canada, Hudson Bay, the Province of Quebec, Vermont, New Hampshire and a portion of the western Atlantic Ocean. This track along which the great oval shadow will travel at about 40 miles per minute, crosses the St. Lawrence valley between the Island of Montreal and just beyond Three Rivers. The western edge of the shadow will be probably somewhere in Notre Dame de Grace, the eastern edge about 35 miles below Three Rivers. The following places are thus well within the path of totality—St. Gabriel, Joliette, Louiseville, Shawinigan Falls, Nicolet, Sorel, St. Johns, St. Hyacinthe, Drummondville, Waterloo, Richmond, Sherbrooke, Coaticook.

In explaining the cause of an eclipse to a child the following points should be made clear by simple experiments, diagrams or models.

(1) Every solid body upon which light is shining from one side, casts a shadow. A round body casts a conical shadow, a

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section of which on any flat surface is a circle or an ellipse according to the inclination of the surface.

(2) The earth travels once around the sun in a year, being sometimes a little more and sometimes a little less than 93 million miles away from it. The sun is a million times bigger in volume than the earth and so hot that it radiates light and heat in all directions.

(3) The moon is smaller than the earth and is a cold solid body. It moves around the earth once every $27\frac{1}{3}$ days, being on the average 240 thousand miles away from the earth.

(4) The earth turns round on its axis once every 24 hours.

(5) There is always a large tapering shadow cast by the earth, and there is likewise a smaller tapering shadow cast by the moon. If the moon gets exactly behind the earth from the sun it passes into the earth's shadow and there is a *lunar eclipse*, the surface of the moon becoming gradually darkened until it is all a dull copper brown. When the moon comes round to the sunny side however, it sometimes gets in direct line between earth and sun and then its shadow may fall upon a small portion of the surface of the earth. But both moon and earth are moving and the earth is also rotating, so that the shadow moves rapidly over a part of the earth before the earth has passed right out of the shadow into full sunlight again. This is an *eclipse of the sun*. Observers situated inside the path of the shadow witness a *total* eclipse, if the moon is near enough to the earth to cover up the entire solar disk. Sometimes the moon is at apogee or furthest from the earth in its elliptical orbit and its surface does not entirely blot out the solar surface but leaves a ring or rim of the sun in view; this is not so spectacular and is called an *annular* eclipse. Observers outside the path of totality will see a *partial* eclipse as the moon moves across the face of the sun obscuring a portion of its surface but moving off again without having covered the entire surface. This too, is an interesting but not a spectacular sight.

(6) We do not get an eclipse of the sun and an eclipse of the moon every month because the plane of the moon's orbit is inclined to the plane of the earth's orbit and so the three bodies do not come into exact alignment twice every month.

The last total solar eclipse visible in Canada was in 1925 from

a narrow strip of central Ontario; previous to that was the 1905 eclipse visible in Labrador. In 1927 the path of totality passed across Central England and southern Norway; in 1929, Sumatra and the Philippines; in 1930, the South Pacific and Patagonia; in 1932 we shall have our own special eclipse; in 1934 an eclipse will be visible in Borneo; in 1936, Greece to Central Asia and Japan; in 1937, Peru; 1940, Brazil, South Atlantic and South Africa; 1943, China and Alaska; 1954, Northern Canada, Scandinavia and Russia. These few facts from tables calculated by an astronomer forty-five years ago will serve to indicate the travelling that must be done if one would attempt to observe several successive total eclipses.

There are several things to be noted in observing a total eclipse of the sun.

(1) Provide yourself with dark glasses or a piece of smoked glass or heavily exposed and developed camera film to observe the partial phases, as until the instant that totality begins, even a small exposed rim fo the sun's surface gives off too much light to be viewed with the unprotected eye.

(2) Watch for the onrush of the shadow, turning your back upon the sun for the moment. In 1842 Dr. J. D. Forbes went to Italy to see an eclipse and he thus described the approach of darkness: "I perceived a black shadow like that of a storm about to break. It was the lunar shadow coming toward us. I confess it was the most terrifying sight I ever saw!"

(3) Watch for the *shadow bands*. Boy Scouts and Girl Guides and adults can provide valuable observations of the fleeting shadows that race along the ground before and after the main shadow. It is best seen if a white sheet is spread on level ground. A few straight sticks should be at hand to place on the sheet indicating the direction of the shadow bands and the line of their motion. They differ before and after totality and with the position of the observer relative to the central line of totality. There is still much to be explained about these shadowy ripples and all careful observations should be reported (Fuller instructions in next issue).

Dr. A. J. Cannon of Harvard Observatory describes the "dance of the mystical shadow bands" at the 1925 eclipse, "I saw them clearly about one minute before totality, and they almost took my breath away. They were narrow pencils, dark greyish . . ." Other

observers recorded "broken waves or ripples paralleling each other and moving with express-like rapidity towards the sun" for 10 or 15 seconds at the beginning of totality, while at the end of totality (which, under different circumstances, may last from a few seconds to several minutes) the direction was not reversed but at right angles to the original direction. All such details as to time, duration, direction will be of value from every point on the path.

(4) Immediately upon totality, the blinding glare of sunlight being cut off, there becomes visible the *corona* or outer radiance surrounding the sun. This appears all around the dark disk of the moon which is obscuring the face of the sun and is thus described by the late Professor Baily, "I was electrified by the sight of one of the most brilliant and splendid phenomena that can well be imagined. For at that instant the dark body of the moon was suddenly surrounded with a corona, or kind of bright glory similar in shape and relative magnitude to that which painters draw round the heads of saints."

(5) Look specially for *prominences*; red, fiery tongues of light at the inner edge of the corona. These are sometimes very fine, sometimes missing entirely. They are due to cyclonic storms in the atmosphere of the sun, hurling glowing hydrogen gas and hot vapours to immense heights, and their bright radiations stand out in marked contrast to the paler softer glow of the corona. Baily describes the prominences visible in 1842 as "red, tinged with lilac or purple . . . perfectly steady."

(6) Watch for "Baily's beads" or the "diamond ring" effect. The surface of the moon being very mountainous, its outline is in some places irregular and hence it is possible for some light from the intensely bright edge of the sun to shine through a lunar valley at the rim of the lunar disk, and this gives a flood of intense light at some point or points around the rim.

(7) A snapshot of the corona and "beads," if any, may be obtained with an ordinary camera. Time exposures of more than a few seconds are unwise on account of the relative movement of earth and sun. Astronomers take as long exposures as they can by means of a clockwork drive that keeps the image stationary by compensating for the rate of rotation of the earth.

(8) The exact determination of the edge of the path of totality

is very important as a check upon the accuracy of the calculations made in advance. It is therefore of special interest if persons situated along the edge will send in records of their observations as to what road, building, hill or other physical feature was definitely in shadow in contrast to some neighbouring building, crossroads, railway track, river, or other feature which can be accurately located on a map, and which was definitely in the sunlight all the time.

(9) Astronomers are particularly interested in the "flash spectrum" just visible for a brief instant at the beginning and end of totality. The spectrum of sunlight is a rainbow-coloured band of light crossed by the narrow dark Fraunhofer absorption lines, but just at totality these dark lines are reversed, that is, they shine out as bright lines, the more intense background of the light from the surface of the sun having been cut off. A pocket spectroscope will show this flash spectrum.

(10) The change in temperature during the progress of the eclipse may be noted, also the degree of darkness may be roughly estimated by noticing what size of type cannot be read—newspaper print and headlines form a handy scale. An observer, in Australia, of the 1922 eclipse reported that by the above methods of estimation it was found that the amount of illumination during totality was equivalent to the light thrown by one candle three feet behind you in a dark room.

(11) Those who are interested in wireless telegraphy may take note of the fading effects which may accompany the passing of the lunar shadow. Radio experts will study this in detail.

(12) It is interesting to notice the effect upon birds, animals, and insects of the oncoming of darkness and the hush of all nature is commented upon by many observers. Definite observations regarding the behaviour of animals, birds, and insects will be of value.

It is not surprising that primitive people have been terrified by a total eclipse and that rites and rituals and even sacrificial ceremonies have been adopted to stay the supposedly malign influences which appear to cut off the light of day.

Near the centre of totality in the coming eclipse the duration of the total phase will be about one and a half minutes. In this

time and just before and after it, astronomers and physicists will make great efforts to obtain photographs of scientific value. Every total eclipse is a challenge to the astronomer to solve a few more of the many problems that the physical nature of our sun presents. There will be elaborate preparations, instruments will be brought over from England by three scientific parties from London and from Cambridge, and Canadian scientists will likewise make every effort to obtain new information and valuable photographs.

There is one critically important thing which, however, no astronomer can arrange beforehand, namely, a clear sky with no clouds. For the sake of the few professionals and the thousands of amateur sun gazers we can only hope and hope and continue to hope that the day may be fair and the sky clear.

N.B.—The writer will gladly receive from any observers, old or young, any observations made carefully and conscientiously, (Address: A. Vibert Douglas, McGill University, Montreal), stating name, address, exact point where observations were made, time and observations.

March 16, 1932.

Note by the Editor—In the next issue, which will appear about July 1, there will be another article giving more detailed instruction for making some of the observations.

MISS CANNON AND THE DRAPER MEMORIAL

THE report of the committee of the National Academy of Sciences recommending the award of a Gold Medal to Dr. Annie J. Cannon gives the following outline of her work.

When Pickering—the second Draper Medallist—was appointed director of the Harvard College Observatory fifty years ago, he aroused the criticism of the conservatives of that day by devoting his remarkable energy and enthusiasm, and the resources of the observatory, to investigations in the physical side of astronomy.

Far from the least among these was the systematic observation and classification of stellar spectra. With a telescope affording a wide field of good definition, and having a prism placed before its objective, the spectra of hundreds of stars can be photographed simultaneously on one plate, so that there was no difficulty in securing observational material. But to record the results of investigation adequately for thousands of stars, and yet in a form not too bulky for publication, was no small problem. If stellar spectra presented the vast variety which is exhibited by living organisms the situation would be almost hopeless; but fortunately they are much less diverse. Hundreds of stars show spectra which are practically indistinguishable from one another under any ordinary dispersion, so that a relatively small number of symbols suffices for the description of the vast majority of spectra. The Harvard observers very wisely decided to make these symbols purely formal, without any theoretical connotation. Mrs. Fleming employed letters of the alphabet, Miss Maury Roman numerals. Miss Cannon —our medallist of to-day—coming to her work a little later revised and refined the former system, and thirty years ago gave it the form which, with trifling changes, is now internationally adopted.

It is generally known as the Draper Classification, for the work on which it was based was supported by the Henry Draper Memorial —a gift to Harvard by the widow of Dr. Henry Draper, a pioneer investigator, who obtained in 1872 the first photograph showing lines in a stellar spectrum. Our academy likewise owes the Draper

Fund and Draper Medal to Mrs. Draper's generosity, and it is especially fitting that we should recognize, by the award of the Henry Draper Medal, the long and productive labours of the investigator who has done far more than all others to give the Henry Draper Memorial the distinguished place which it occupies and must permanently continue to occupy in the history of astronomy.

Miss Cannon's introduction to her first "Catalogue of the Spectra of 1,122 Stars" describes the criteria upon which her classification is based so well that it has ever since been the standard authority upon the subject. No clearer statement could be made to-day of the great principle upon which the system is based—that almost all stellar spectra can be arranged in a continuous linear sequence. Though the spectra of stars near opposite ends of the sequence—for example, of Sirius and Arcturus—are so unlike that they seem at first glance to have hardly anything in common, yet a succession of stars can be found whose spectra differ from one another by barely perceptible degrees, and together form a complete transition from one to the other, and this transition is always through the same intermediate stages—there is no alternative path.

The older classification had assigned letters of the alphabet to various more or less obviously different spectra, as they appeared on the photographs. The newer dropped from the list those letters which proved to correspond to poor photographs or unimportant differences, and in some cases rearranged the order to agree with that of the linear sequence whose existence had become unquestionable.

By the survival of the fittest, the letters O, B, A, F, G, K, M were left to represent standard types along the sequence. Intermediate spectra are represented in the Draper Classification by a decimal notation, B0, B2, B3, B5, B8 being successive stages in the transition from B to A. The resulting system has proved so convenient that all it has since required is the addition of affixes to take account of certain details which had necessarily to be ignored in the pioneer work. With this admirable system at hand, our medallist faced a task which might have appalled even the stoutest

heart—the observation and classification of the spectra of all the stars in the heavens which could be photographed with the instruments of the Harvard Observatory—at that time the most powerful in the world for this purpose. It was no longer a question of thousands of stars, but of hundreds of thousands. The mere mechanical arrangement of the work, the identification of the stars, the recording and indexing of the observations, demanded careful planning and extensive clerical assistance.

This labour of years culminated in the publication of the nine volumes of the Henry Draper Catalogue, which give the positions, magnitudes and spectra of 225,300 stars, covering the whole heavens from pole to pole, and including all the stars brighter than the 8th magnitude and many which are fainter. Every one of these spectra has been examined and classified by our medallist in person. There is probably no other instance in the history of science where so great a mass of important data has been obtained by a single observer on a homogeneous and uniform system.

With the completion of the great catalogue seven years ago, a less devoted observer might have felt justified in resting. But improvement in observational technique had made it possible to photograph the spectra of fainter stars, and so the "Henry Draper Extension" was begun.

This extends the observations down to magnitude 11.5, and sometimes below. The number of stars which might be observed is now so great that it is impracticable to wait until the whole heavens have been covered, and then publish a general catalogue, and the results for various regions of the sky are being published as they are obtained. About one hundred thousand spectra have already been classified, and the work still continues. Long may it prosper!

The value of these great catalogues can hardly be overstated. Knowledge of the spectral type must lie obviously at the very foundation of any investigation of the colours, temperatures, real and apparent diameters and physical constitution of the stars. It has proved to be of almost equal importance to the investigators of their distances, motions and distribution in space.

Even in such an apparently local problem as the determination of the solar parallax by observations of an asteroid, the observer must know the spectra of his reference stars if he is to avoid the peculiarly troublesome errors which come from differences in colour of the stars and of the planet. It is, indeed, hard to specify any branch of the study of the stars in which these great catalogues of spectra are not already almost indispensable.

With these consequences of her work—fascinating as they are—our medallist has concerned herself but little. True to the ancient tradition of the observer, who labours cheerfully for the joy of the work, and only rejoices the more that other men of different interest will enter into his labours and base their own upon them, she has used her unique skill and experience in the steady accumulation of a great addition to the permanent capital of astronomical science—a fund which, itself remaining intact, will continue to produce income in the work of astronomers yet unborn, who may well "rise up and call her blessed."

THE UNIVERSE AS A WHOLE*

By A. S. Eve

TO speak of the "Universe as a Whole" is at all times difficult; to do so in fifteen minutes is presumptuous! So I hope that my readers will sympathize with me.

We all look at the universe, everything that is, each through our own spectacles. To some it appears to be a magnificent game, to others a terrible battleground. In form and aspect it is varied and wonderful, teaming with perpetual novelty. Sometimes it seems like a place where marvellous and gigantic experiments, of vast importance and extent, are continually in progress.

Many have asked, and are asking still, "What is it all for? What is the object of it"? I am not sure that we can ever answer that question, we are too intimate a part of the universe to be able to describe the whole. "Shall the clay say to the potter—Why hast thou made me thus"?

We might ask too whether the universe had a beginning. What was the origin? Whence did it come?

If we speak of the material universe the consensus of opinion has usually been in favour of a Creator or Author, and many believe in a Sustainer of the Cosmos or ordered whole, and in such sense that the universe is still being created, the new from the old continually.

But if we include under universe both Creator and Created, then we cannot imagine a beginning at all, it is not a thinkable experience. It does appear, however, that the material universe has had a beginning, that now it is middle-aged, and very slowly approaching inevitable decay. That is the present position of most scientific men, judging by the evidence now available; although it is fair to state that there are some men who think that nature runs itself from an infinite past to an infinite future—an idea quite

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difficult to the present speaker. Is it not more reasonable to regard the universe as the great laboratory of an inconceivably great master mind, wherein we can only partly appreciate and understand a fragment of the great plan?

There is one interesting question, however, to which an answer is being attempted with some measure of success—the question of the size or bigness of our universe.

In order to understand this you might imagine yourself back in the days when people thought that the earth was flat, and laughed heartily at the idea that it was round. For how could people on the other side stay on the earth head downwards? And again—would not then all the waters in the wells, say in China, spill out over the ground!

A man standing on that old flat earth would point along the ground and say, "What if I go ever so far in this direction which I now choose?" Well, the answer was that he would come to the sea, and onwards to more and more sea; for if there was a barrier, what was behind the barrier? Yes, the sea must go on for ever!

We know now that this was wrong, and that if you fly north in an aeroplane at 158 miles an hour from Montreal, in 20 hours you would be at the North Pole, and that, going straight on, you would be flying south and reach the equator in 40 hours more. Another 40 hours would take you to the South Pole, and, flying straight on, you would pass the equator going north and be back again at Montreal in less than a week! If you had enough gas and endurance you could fly right round the earth in less than a week!

In just such a way to-day a man can point to the sky and say, "What should I come to if I went on and on for ever in that direction"? Travelling with the velocity of light you would go as far as the moon's distance in a second and a half, the sun's distance in eight minutes, the nearest star's in four years, perhaps past the North Pole Star in 40 years, out through the great group of stars which you see in the Milky Way, forming our group of stars, or galaxy. Thence after millions of years to other groups or galaxies, and after many hundreds of millions of years you would, most probably, and not after an infinite time, mark you, return, yes,

return you would, though always moving straight on, back you would come to this earth, or rather where the earth was when you started! You would have circumnavigated the universe as our airman flew round the earth.

Some men have said that if you could see far enough you would see the back of your head! But that is not true. Rather you might see where the back of your head was a few hundreds of millions of years ago! It would be quite interesting to think where it was then! In any case, just as you can wander continually on the surface of the earth, by boat and coach, because it is of finite size but has no boundaries, so too the universe is probably finite but unbounded.

Recent discovery seems to show that the universe is expanding because the great distant groups of stars, or galaxies, appear to be moving away from us with astonishing speed. If you take a toy balloon, put black marks upon it, and blow it up larger and larger, then the black dots will get further and further away from you, and from one another. Something of the same sort seems to be happening to the great star groups. As they move very fast away from each other this expansion cannot have been happening forever, and indeed their high velocity indicates that the "age of the universe" is much less than was quite recently supposed, although in any case it must run to thousands of millions of years! It is right to explain that the "age of the universe" does not mean the time from a date when there was nothing at all; it means rather the time from when the present order of things first marched in the direction they are now travelling or evolving.

Lest anyone should feel appalled by the immensity of the universe, with its millions of galaxies, each containing hundreds of millions of stars, let him remember that small things are excellently well ordered; that a hair, a fragment of a feather, or leaf, seen under a microscope shows most elaborate organization; and that every atom is a microcosm, that is a little universe in itself, as fresh to-day perhaps as myriads of years ago.

So far we have been thinking of the physical universe of stars and planets, atoms and the space between them. Far more interest-

ing, and probably more important, are living things which get their sustenance from air, earth and water, but are different from these, for after all a stone is different from a tree, and a tree from a lion! There do not seem, among the vast number of stars, many suns like ours which have a planet like the earth kept for long years between the boiling and freezing points of water, a region of temperature probably essential to life. We are at once astounded that life should have originated on, or come to, this planet, and that such infinite variety should have developed on the land and in the water.

Jeans has pointed out that life cannot be a main object in the universe, but rather a side show, because so small a region is set apart for living things. But bigness is not everything, and many men will treasure some small garden of roses, or a precious herbaceous border, more than the long wide sweep of grass or lawn.

It is stranger still that man, with his full consciousness and high reasoning faculties, should so far have transcended the other animals, and that these should culminate in the giant intellects of such men as Shakespeare, Newton and Einstein.

To speak of the universe as a whole without reference to things spiritual and eternal, transcending the finite and material, would surely be misleading. Perhaps this is not the time to enlarge upon this theme nor the place. Yet if there be a Oneship, or Unity, between Creator and Created, there is a link which it is the special privilege and glory of man to be able to appreciate and to understand.

Returning now to the ways of nature it is indeed interesting to note how the same material and the same energy may be used again and again to make and remake the multitudinous forms and varieties of things both living and dead. Those who have gardens know well the use of leaves and leaf-mould to secure vigorous plant growth, and those who have farms realize the importance of fertilizers whether of plant, animal or mineral origin. There must be nitrogenous and phosphate material in the soil to grow good crops and hence to raise good stock.

Nature does this on a vast scale. Take such simple cases as air and water. The oxygen we breathe continually has been a part of innumerable plants and animals down all the past ages of the

earth, since life appeared. Consider again a small particle of water, a single molecule as it is called. If such a water particle could speak of its past history, what a romantic tale of travel it would tell! It has visited every ocean on the earth, it has been lifted time and again by the heat of the sun, it has condensed into cloud, fallen as rain on every continent, and travelled back to the sea by countless rivers. It has been frozen in the Arctic and Antartic ice, and floated in icebergs, ever moving and circulating. It has been a part of numberless plants and of innumerable animals historic and prehistoric in type.

My hearers themselves are indeed in the same condition as the Archbishop of Canterbury, shall we say, who Sir Arthur Shipley humorously said, is ninety per cent. water! So that many of you must contain water molecules which have not only been great travellers, but have been now in plant, now in animal, and a few peradventure, were once incorporated in Napoleon, or Newton, or Julius Cæsar, or anyone you like to choose.

By this reusage of matter and energy life continually passes through cycle after cycle from spring to winter and back to spring, drawing ever fresh supplies of energy from our great powerhouse, the sun. Similarly it is possible, but not certain, that our present material universe may have had a "beginning," that it is now in middle age, and approaching that old age when energy and radiation, all present, are no longer "available," except by a new "beginning" and a fresh spring. But here we are speaking of things as yet unknown to us, and it is wiser to go on exploring nature in our quest for truth, which alone can make us free, and to discover of the universe that indeed "My lot has fallen on a fair ground, yea! I have a goodly heritage."

WHAT DO WE KNOW ABOUT STARS?*

By A. Vibert Douglas

WE know a great deal about the outsides of stars, the physical conditions existing in their gaseous atmospheres, but we know very little about the deep interiors of stars. We know a good deal about their numbers, their distribution in clusters and galaxies, their motions, and their course of evolution from infancy to age.

Let us ask and attempt to answer as briefly as possible some specific questions.

What are the stars? Each star is a vast, more or less spherical aggregation of matter, partly if not entirely in the state of incandescent gas. Some astronomers think that deep down beneath the gaseous outer layers the matter may be in liquid form, others think it is gaseous to the very centre. Certainly the outer layers are composed of gases, of this there is no doubt, for the light which comes out of the stars, when studied with a spectroscope, exhibits just those characteristics which are found in the light produced from various gases in the physicist's laboratory when these gases are raised to incandescence by the application of heat or by the excitation of an electric discharge. And this is one of the astounding secrets of the Universe, revealed by spectroscopy within the last century, that almost all the elements—iron, carbon, oxygen, hydrogen, silicon, calcium, and so on,—which go to make up the earth, are found to be the stuff of which the stars are made. There is no perfect, unchanging, unchangeable substance composing sun and stars, as the Greek philosophers maintained,—the whole universe is made up of similar aggregations of the two fundamental entities, the electrons and the protons which are the ultimate negative and positive electrical charges of which all the elements,—all matter,—all things animate and inanimate—are made.

How large and how heavy are the stars? A super-giant star,

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like Antares in the constellation of Scorpio or like Betelgeuse in Orion, is several hundred million miles in diameter. If its centre were coincident with the centre of the sun, half the Solar System would be inside the star. Thus the volume of one of these great stars is several million times that of the sun, and the sun's volume is one million times that of the earth. But the density of such a star is very low, much less than that of the air we breathe, and so its mass, or the amount of matter it contains, is only ten or twenty or perhaps thirty times that of the sun. Very few stars are known to be more massive than this. At the other extreme are the stars about one-tenth as massive as the sun, and so dense, so compacted into very small volume, that one cubic inch of such a star would weigh a ton on our terrestrial scales.

It is just because the stars, even the smallest of them, are so massive that they are able to retain their heat, and hence their ability to radiate light and heat for many millions of years, whereas relatively small aggregations of matter like the planets of the Solar System have cooled off and ceased to radiate.

How hot are the stars? The radiating surface of the coolest star is at just about the highest temperature producible in an electric arc. The light emitted by such stars, like Betelgeuse in Orion, contains a large proportion of red rays. Hotter stars, like our sun, whose surface temperature is about 10,000°F., shine with a yellow or golden light. Still hotter stars like Vega emit that harmonious blend of all the visible rays which we recognize as white light, while the hottest known stars like Rigel in Orion, shine with a steely blue light.

We cannot measure the central temperatures directly, but all theoretical calculations point towards internal temperatures of many millions of degrees. The interior of a star is pictured as a vast storehouse of energy where the material atoms are in some unknown manner being transformed into radiant energy, and this radiation rushes outward like a mighty wind. Four million tons of the sun's mass are being transformed every second into radiation to supply the stream of heat and light and invisible ultra-violet rays pouring out continuously into surrounding space.

How old are the stars? Suppose an observer with no knowledge of the past looked suddenly upon the world of humanity, he would see infants and children, youths with strength and vigour, men whose powers were fully developed, and yet others whose strength was on the wane. Seeing many at every stage from infancy to old age, he might, perhaps, hazard the guess that with the passage of time each individual passed through one stage to the next—an evolution of man from cradle to grave. So, too, the astronomer sees stars in their infancy with latent undeveloped potentialities, stars whose energy output is that of vigorous youth, stars at the peak of their vitality, stars on the wane, on the descending road towards inactivity and darkness. Can he avoid the hypothesis that there is a majestic evolution of the stars? The evolution of a man takes place to the ticking of the seconds hand, hour by hour for four score years, but the evolution of a star requires a different time-scale.

In a vast region of space, sparsely filled with nebulous matter, concentrations begin inevitably to take place and gravitation draws more and more matter towards each centre of concentration,—thus is born a cool, diffuse star. As it grows more massive and more compact its internal temperature of necessity grows greater and it begins to radiate more and more vigorously. It ceases to grow indefinitely more massive when the outward hurricane of radiation blows off the surface layers as fast as gravitational attraction augments them. The star is now of giant proportions, but as it continues to contract and radiate away its energy, it passes in due time into the dwarf stages of its career. Gradually its course of evolution brings it to a stage where its mass is greatly reduced, its energy largely expended, its ability to radiate almost, or perhaps entirely, gone. This evolution takes place to the beat of units of time measured not in seconds but in millions of years.

This is not a sad picture any more than should be the picture of the evolution of a human being from infancy to age, where faith stands firmly on the principle of conservation of spiritual values. The energy of the youthful, giant star is gradually transformed and dissipated and the star becomes old and cold and

outwardly inactive—but its energy is not lost—the Law of the Conservation of Energy is a fundamental bulwark of physical science. We do not know what ultimately will become of this energy. Is it, perhaps, used up in the process of the expansion of space itself? Here is an unsolved problem. The universe of a far remote future may be very different from the universe of to-day. Nature has many secrets as yet hidden from us.

Is the sun a typical star? The answer is both yes and no. The sun is in itself quite an ordinary dwarf star—there must be thousands just like it, and there are many stars somewhat smaller and many that are larger. It is, however, a star with an exceptional history. Some 2,000 million years ago it befell that another star approached very closely to it, perhaps even collided with it, and as a result the sun lost a portion of itself. These disrupted gases gradually condensed to form the system of planets and satellites, comets and swarms of meteors which revolve in their respective orbits about their parent sun. These planets in order of proximity to the sun are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto, the recently discovered outermost planet.

This disruption of a star is a catastrophe so improbable in the universe that it is almost certain that very very few stars have thus acquired an attendant retinue of planets. For though the stars are all moving in various ways through space, often with exceedingly high velocities, yet their relative separations are so tremendous that the chance of a collision is extremely small. Imagine four or five little minnows as the sole inhabitants of the Atlantic Ocean into which they have been thrown at various places, from north to south, from Europe to America. Here is a picture of the distribution of stars in our galaxy. The chances of a collision are obviously very small. Theoretical calculations alone are useful in a search for other solar systems, for so distant are even the nearest stars that no telescope could reveal such planets as those surrounding our sun even if these neighbouring stars were to possess such an entourage.

How many stars are there? With the naked eye one can rarely

see more than about 2,000 stars at one time. Altogether there are some 6,000 visible without telescopes. But with powerful telescopes and long exposures, photographs have been obtained of many million stars. Astronomers calculate that around our sun in this great galaxy there are some ten thousand million stars.

Far out in space beyond our great galaxy there are yet other star galaxies, perhaps not quite as large as our own, but large enough to contain star material equivalent to a thousand million suns in each galaxy. Much of this material is as yet in the form of primeval nebulosity, while much of it has already condensed into stars. The vastness of the universe baffles our imaginations.

What is our debt to the stars? Our earth was once a portion of the surface material of the sun, and the sun, as we have seen, is just one star amongst the many millions of stars of a great galaxy. A chance fragment of a star is our planet, and man, as far as his physical framework is concerned, being "of the earth, earthy" is therefore of the stars, starry! Or, rewriting a famous line of the great poet, "We are such stuff as stars are made on."

When we seek the source of the energy which maintains the surface temperature of the earth at a reasonable degree of warmth, the energy which makes possible the existence of life upon the earth, we find that almost all this energy comes from without. It is brought to the earth in the sunlight and in the starlight, but since the term starlight in its strictest sense includes sunlight, we may simply say, and with absolute scientific accuracy,—Of star dust are we made and by starlight we live.

Perhaps you would remind me that man does not live by bread alone. To which the astronomer would make reply that if you are seeking food for the spirit of man, one of the unfailing sources is to be found in the contemplation of the beauty, the harmony, the majesty and the deep mystery of the Universe of Stars.

REVIEW OF PUBLICATIONS

Le Calcul des Différences Finies et ses Applications, by Alfred Henry, member of the Actuarial Institute of London, translated into French by A. Sallin. 212 pages 6¼ x 9¾ inches, Paris, Hermann. Price 50 francs

The calculus of finite differences is a subject which has not received the attention in Canadian Universities that it deserves, Outside of the students who are specializing in actuarial science. very few obtain any instruction in this application of mathematics. It finds a great many applications in astronomy where the functions representing the variables, positions, times, etc., can not be represented by mathematical formulae but are tabulated for finite intervals of time.

Methods of interpolation, mechanical integration, rates of variation, are presented in a concise form and the last chapter gives some applications to the theory of probabilities. Very numerous examples are worked out and there is a generous list of problems at the ends of the chapters, with their answers. The book will serve as a very good text, either in the class room or for the student desiring to obtain a knowledge of the subject for himself.

R.K.Y.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

General Index to the Journal

In the December issue for last year it was stated that Mr. W. E. Harper was preparing a *General Index* to the first twenty-five volumes of the Journal and the previous publications of the Society, which date from 1890. It will be published during the coming summer. Names and subjects are arranged in a single alphabetical index, and Mr. Harper has spent much time and care in trying to make it complete and accurate. It will contain about 125 pages and the price will be $1.00 (by post, 5 cents extra). The edition will be limited and it is hoped there will be a good demand for it as the cost of publication is considerable.

Chronology for the Times

A suggestion for a new style of chronology comes from a well-known American educational institution in which, following the prevailing fashion, there has been a sharp reduction in salaries. It is proposed that B.C. shall signify "Before the Cut," and A.D., "After the Depression."

Bright Fireball Seen from Toronto

Two observers describe a brilliant fireball seen at 10.40 p.m. (E.S.T.), March 28, 1932.

Mr. F. L. Troyer, at Bloor and Bay Streets. Magnitude about —6; first observed in approx. R.A. 10.5 h., Decl. 2°S. (approx. at a point in Leo found by producing a line through epsilon and alpha Leonis its own distance). Last seen passing behind a cloud in altitude about 45° and 15° east of south. Duration, 2.5 sec. No train observed, possibly on account of haziness of sky and bright lights in the vicinity and down the street.

Mr. C. Plummer, on Roslin Avenue, in North Toronto. Seen about 40° above the horizon and 10° east of Alpha Hydrae, almost due south (The north-south streets of Toronto are inclined about

15° to the meridian—*Editor*). It began of a dull red colour and as it fell a bright red tail streamed out. Its head changed from dull red to bright red, then to white and finally to bright blue. The tail elongated until about 20° in length. The head moved about 10° easterly and was about 20° above the horizon on disappearing. It looked like a large rocket when ascending, with its fiery head and long shining tail. Duration, fully 5 seconds. "The remarkable thing about this body was the change, as it fell, from dull red to brilliant blue and the apparently slow pace at which it travelled. There was ample time to watch it develop in length, increase in brightness, observe the nature of the long tail, and watch the wonderful change in the colour of its head. I noticed a few other meteors during the evening, but they were gone in a flash."

THE SOLAR ECLIPSE OF AUGUST 31

In this JOURNAL for December, 1930, there was published a map showing the position of the shadow at one-minute intervals as it will pass across the province of Quebec. In case this map is not available the following description of the shadow-belt may be useful. The eastern limit of the path of totality passes near La Tuque, P.Q., crosses the St. Lawrence river forty miles west of Quebec city, enters Maine near its boundary with New Hampshire, continues over the Rangeley lakes and reaches the Atlantic coast at Boothbay, Me. The western limit crosses the Gatineau river where the latter enters Joliette county (Lat. 47½ N.), passes through the western part of Montreal, crosses the upper end of Lake Champlain and passes near St. Albans, Vt., Montpelier, Vt., Concord, N.H., Salem, Mass. and Chatham, Mass. The central line crosses the Quebec-Cochrane branch of the Canadian National Railway, six and a half miles east of Parent, passes three miles west of St. Alexis des Monts, crosses the St. Lawrence near Maskinonge and Pierreville, fifty miles east of Montreal, passes one mile west of Magog, enters the United States a few miles east of Rock Island, passes one and a half miles east of the summit of Mount Washington, N.H., two miles west of Fryeburg, Me., and reaches the coast at Cape Porpoise, two miles east of Kennebunk Port, Me. The width of the belt is about 100 miles and the duration of totality about 100 sec. According to the chart in the February, 1932,

JOURNAL, the prospects for clear sky at 3.30 p.m., the time of the total phase, are rather better in the southern part of the province than farther north, but it is very desirable that observing parties be stationed all along the path.

News of plans for observations has appeared in various publications. The Dominion Observatory, Ottawa, will send an expedition to Parent. They expect to use a lens of focal length 45 feet and two of 10 feet; also one of focus 40 inches, with an objective prism. They also propose to take a motion picture of the eclipse for possible reproduction and for determining the times of contact. This expedition will be accompanied by a party from the Royal Observatory at Greenwich, consisting of Dr. and Mrs. J. Jackson, Mr. and Mrs. C. R. Davidson and, somewhat later, will be joined by Dr. H. Knox-Shaw of Oxford. Prof. F. J. M. Stratton of Cambridge University, England, will head a small party at Magog. He will be assisted in his spectroscopic work by several scientists from McGill University, and the Department of Militia will loan and erect suitable tents for the party. Professors Alfred Fowler and Herbert Dingle, of the Imperial College of Science and Technology, London, England, will make spectroscopic observations from the roof of the Macdonald Physics Laboratory of McGill University, which is just within the shadow belt. At Sorel an expedition from the Leander McCormick Observatory, under the veteran eclipse observer, Prof. S. A. Mitchell, will be located. An expedition from the University of Toronto will observe at St. Alexis. It proposes to use cameras of focal lengths 40 and 11 feet; also a polariscopic camera with four lenses and two nicol prisms. Attempts will be made to photograph the shadow bands and special photometric apparatus will be used. In addition motion pictures will be made by a member of the Ontario Motion Picture Bureau which is actively assisting in the preparations.

Many United States parties will observe in the neighbourhood of Conway, N.H., and Fryeburg, Me. Parties from the Lick Observatory, Cal., and the Sproul Observatory of Swarthmore, Pa., will go to Fryeburg. Near Centre Conway will be an expedition from the Van Vleck Observatory of Middletown, Conn. The Franklin Institute of Phildaelphia will have observers at Conway, and the Perkins Observatory of Delaware, Ohio, will locate at

Douglas Hill near Sebago, Me. At the latter place there will also be some members of the Royal Astronomical Society. Expeditions from the Mount Wilson Observatory, the University of Indiana, the Kwasan Observatory of the Kyoto Imperial University (Japan), and the famous Pulkova Observatory, Russia, are also expected. Members of the Royal Astronomical Society of Canada, at Toronto, are organizing several parties which will probably observe near the St. Lawrence on the north and the south side.

The effect of the eclipsed sun on radio signals will be observed by the Canadian Marconi Co. and the Northern Electric Co. In the case of short waves, say of about 90 meters, the waves do not travel along the ground, which indeed absorbs them, but go up into the air and are reflected from the lower Heaviside layer at a height of about sixty miles. In many cases, however, reflection takes place from another layer about twice as high. It is believed that these layers are made conducting (and hence able to reflect the electric waves) by the ultra-violet light from the sun; and hence they will be affected by the eclipse, since the time of totality will be similar to a brief period of night. It is very desirable to determine what changes take place. It may also be remarked that the height of the Heaviside "ceiling" has never been determined in Canada. The general organization of the radio investigations is in the hands of Col. W. A. Steele, of the National Research Council, Ottawa, and McGill University is actively co-operating in the work.

The Dominion Observatory at Ottawa has issued a pamphlet containing information regarding the eclipse, including a list of suitable sites for observing with a description of accommodation to be obtained there. Copies will no doubt be sent on application to Director Stewart.

C. A. C.

THE NEW CENTRE AT EDMONTON

By R. A. GRAY, *General Secretary*

TWO new Centres of the Royal Astronomical Society of Canada have recently been organized, one in Vancouver, a report of which appeared in the January issue of the JOURNAL; the other at Edmonton, Alberta.

On October 19, 1931, Dr. J. W. Campbell of the University of Alberta communicated with Prof. Chant requesting information on the proper procedure to be adopted in initiating a branch of the Society. Information was gladly given and copies of the Constitution and By-laws were forwarded.

On January 14, 1932, an organization meeting was held in Edmonton at which a large number of people interested in astronomy were present, and on February 3 another meeting was held at which nearly sixty signed a petition to the General Council requesting permission to form a new Centre at Edmonton.

This petition came before the Council on March 18 and authorization was granted by the Council to form a Centre, provided that the required conditions were complied with. As the conditions have been fulfilled the Centre was established.

To encourage the new Centre during the first year of its existence the Council made an immediate grant of one quarter of the fees received and in addition decided to return one half of the fees for 1932 when the grants are made to the several centres at the close of the year. A list of the members was then forwarded to Toronto with the necessary fees.

At a subsequent meeting in Edmonton the following officers were elected:—President, Dr. J. W. Campbell; Vice-President, Prof. E. S. Keeping; Secretary, Miss Frances Fisher, 10953–123 St.; Treasurer, Dr. E. H. Gowan; Councillors, Father Englebert, Mrs. J. G. Taylor, Miss M. Simpson, Capt. H. J. Towerton, Mr. K. F. Alexander.

MEETINGS OF THE SOCIETY

TREASURER'S REPORT, TORONTO CENTRE, 1931

(Omitted from Report of General Meeting in March issue)

RECEIPTS

Balance from Statement, 1930	$ 14.18
Grant from Toronto City (One year refunded by General Soc.)	200.00
Grant from General Treasurer	152.50
	$366.68

DISBURSEMENTS

Rent, University of Toronto	$ 62.50
Dr. Plaskett, lecture expenses	38.00
Printing, Announcements, etc	67.08
Harvard Telegrams	12.15
Postage, Stationery	23.42
Balance in Bank, December 19, 1931	163.53
	$366.68

Audited
A. R. Hassard
J. B. Fraser

(Signed) W. M. WUNDER,
Treasurer

AT MONTREAL

October 22, 1931.—The meeting was held in the Macdonald Physics Library at 8.15 p.m. The president, Dr. L. V. King, occupied the chair.

The Annual Reports of the Secretary and Treasurer were presented and accepted. The election of officers took place (as previously reported).

It was moved by Mr. G. Harper Hall that the thanks of the Society be extended to the Director of the Macdonald Physics Laboratory for his generosity in giving the Society the use of the Lecture Theatre. Dr. Eve made a brief acknowledgment.

Election of new members:—

Dr. C. W. Hendel.

Mr. E. E. Duckworth.
Mr. J. J. Cooper.
Mr. H. M. S. Lewin.
Miss M. S. Kennedy.

Dr. A. V. Douglas was then called upon to give an address on "Theories of Cosmology—Ancient and Modern."

The lecturer described and illustrated some of the very early picturesque theories of the universe held in Asia, Africa, and Europe before the time of Copernicus. Then followed an account of the advances in astronomical knowledge and cosmological outlook to the end of the 19th century. The revolution in thought which followed the early work of Einstein, leading to the subsequent work of himself, of Minkowsky, de Sitter, Weyl and Eddington and most recently Lemaitre was dealt with at some length and the present outlook with its remaining problems was described.

November 20, 1931.—The meeting was held at 8.30 p.m., jointly with the McGill Chapter of the Sigma Xi. Prof. F. E. Lloyd, President of the Sigma Xi, was in the chair.

The lecturer was Dr. Willem de Sitter, Director of the Leiden Observatory, Holland. His subject was "The Nature of the Universe and the Expansion of Space."

Is the Universe infinite? Archimedes, "the greatest of great mathematicians," said "No," and his proof was that if you think of it as being filled with grains of sand, there must come a time when not one more will fit in. Archimedes introduced into thought the ideas of continuity and infinity.

Slides of the Milky Way and Spirals suggest a similarity. The view that our galaxy is a spiral was first proposed by Dr. Easton.

Kapteyn's star counts revealed much regarding our local cluster, often called the Kapteyn System (K.S.). Later work showed that the 90 or so globular clusters all lie to one side of the K.S. and still later work shows the K.S. to be in rotation about a galactic centre probably coinciding with the centre of the globular clusters. For some the period of revolution is 2×10^8 years and the force varies inversely as the distance from centre; actually 95% mass of the galaxy lies near this centre. Lord Rosse (1845) used his 72-inch telescope to study spirals, seeing actual stars, not merely gaseous matter.

The fact of the recessional velocities of the spirals was then discussed in the light of the expansion theory. They would double the radius in 1400×10^6 years.

It was pointed out that there is a logical development of ideas from Galileo's Inertia to Newton's Mechanics and Einstein's Relativity. The former involve differential equations of the second order and show them to be necessary and sufficient. The latter shows why gravitational mass is the

same as inertial mass. By 1917 there were two solutions of the differential field equations, (a) Einstein's, or the "Static" Universe—finite, but no systematic motions possible. Its value is determined by R (radius), and M (mass) varies as R; also density varies as R. (b) de Sitter's or the "Empty" Universe—also finite, involving R; it has systematic velocities and expansion, but no mass. Which is the correct model? Is our actual universe empty or nearly so, or full of matter?

Fifteen years ago we knew nothing much outside the K.S., which is 100,000 l.y. across. Now we have data up to 10^8 l.y. Assuming the universe homogeneous and isotropic, we find density is 2 or 3 atoms per cu. ft., *i.e.* 10^{12} times emptier than the best vacuum. But relative to the Einstein density for a full universe, ours is 1/3 full, therefore far from empty. The Lemaitre solution allows for a variation of R with time. From spirals, we get the rate of change of the radius and hence calculate back to original radius. We find the time is too short for our customary scale of time of stellar evolution.

This is a difficult problem, but we shall grow accustomed to facing two time scales, independent, but running contemporaneously. The Lemaitre theory will stand but our interpretation of its significance will probably change.

A. VIBERT DOUGLAS, *Secretary*.

AT VICTORIA

January 29.—The meeting was held at 8.00 p.m., the President, P. H. Hughes, in the chair and about fifty members and friends present.

Mr. Charles Hartley gave a five-minute talk on Sirius, following which Dr. J. S. Plaskett gave a most interesting and instructive talk on "Diffuse Gaseous Matter in Space".

Sir William Herschel's observations on the luminous nebulae and Barnard's discovery of the dark nebulae about 1900 were followed in 1904 by Hartmann's discovery that the H and K calcium lines in the spectrum of Delta Orionis did not belong to the star, leading to the hypothesis of an intervening cloud of calcium gas. Working in 1923 on spectra of the hottest stars in the Milky Way, Dr. Plaskett found this calcium gas to be widely distributed throughout the galaxy, the stars moving independently through it. Studying Plaskett's work, Eddington in 1926 discussed mathematically the properties of this interstellar gas, showing that it was so exceedingly tenuous that a globe of it of the volume of the earth, 250,000,000,000 cubic miles, would only weigh 4 ounces and that it must be at an "effective" temperature of 20,000°K. Recently this theory has been definitely confirmed and difficulties removed by the work of Dr. J. A. Pearce, who with Dr. Plaskett, showed that this diffuse gas was uniformly distributed throughout the galaxy, and was in rotation along with the galactic stars around a centre so remote that, though moving at 200 miles per second, required 250,000,000 years to complete a revolution.

In tendering the thanks of the meeting to Dr. Plaskett for his lecture the President remarked that this work, done mainly at the Dominion Astrophysical Observatory here, was one of the most important developments in cosmogany.

February 26.—At this meeting with President P. H. Hughes in the chair, some 80 members and friends being present, N. C. Stewart gave a five-minute talk on Ursa Major.

The following were elected to membership:

H. J. Morgan, Calgary, Alberta
A. J. Bird, Victoria, B.C.
Horace E. Moore, M.A., Victoria, B.C.
E. W. Mutch, Penticton, B.C.

The President introduced the lecturer H. D. Parizeau, Divisional Hydrographer, Department of Naval Service, who spoke on the Hydrographic Survey of the Coast of British Columbia. Mr. Parizeau traced the charting of the British Columbia coast waters from the work of the first explorers, Perez, Cook and Perouse, many of whose maps were shown by lantern slides, through the period of the early trading ships to the present day governmental surveys, and noted the accuracy of much of this early work. The work of the hydrographic survey was described, the lecturer explaining the determination of a base line, how positions are fixed and triangulation carried out, the correlation of this work with that of the geodetic survey, sketching of the appearance of land as the coast is approached, how in-shore sounding is done by a hand-line and off-shore by the sounding machine whereby much time is saved in deep sounding work, and the latest adaptation of radio in the radio depth finder and radio accoustic ranger.

Improvement in the legibility of charts was shown by comparing an uncoloured admiralty chart with the same chart coloured to show the depth ranges and channels. Importance of drag sweeping for submerged pinnacles was emphasized.

The meeting concluded with a vote of thanks to the lecturer for his most interesting talk.

H. Boyd Brydon, *Sec.-Treas.*

The Royal Astronomical Society of Canada

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A GENERAL INDEX

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